A hybrid power plant with the synchronization controller system for saving electrical energy use (research study at the campus of the State University of Gorontalo)

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Article Info

Article history:

Received Jan 7, 2025
Revised Apr 7, 2025
Accepted May 30, 2025

Keywords:

Design
Energy saving
Hybrid
Power plant
Synchronization controller system

ABSTRACT

The electrical energy network in the campus of the State University of Gorontalo is supplied by the grid system of the state electricity company. The average electricity used in 2022 was 95,461 kWh, with a monthly payment fee of 83,067,250 IDR. Because the cost of paying for the use of electrical energy is relatively high, the researchers consider it necessary to make efforts to save the use of electrical energy by utilizing renewable energy sources. This study aimed at planning a hybrid energy power plant by combining solar energy and government electricity grid connection with electrical power divider settings using a synchronization controller system. The method of this study was designing hybrid power plants and analyzing investment needs and return on investment (ROI) using the life cycle cost analysis (LCCA) model. The results showed that the design of the hybrid power plant with a synchronization control system used at the campus of State University of Gorontalo in Bone Bolango Regency in September 2022 during the sun irradiation at 06.00–18.00 presented that the photovoltaic (PV) system could generate 57.575 kVA electrical power. Or can divert electrical load to the PV system by 55.40%. Electrical energy saved from January to September 2022 was 426,975 kVA with a cost of 614,844,000 IDR or 82% of the previous payment for electricity usage. The investment required for the hybrid power plant's construction, operation, and maintenance are 10,747,886,800 IDR. The ROI of the power plant can be obtained up to the 13th-year period.

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1. INTRODUCTION

A serious problem currently faced by all countries in the world is the supply of energy to meet energy needed by society, government, industry, schools, and campuses [1]. Dependence on electrical energy to support the needs of life and daily work will be difficult to fulfill if it is not supported by the availability of adequate electrical energy. The need for electrical energy will continue to grow along with the increase in the number of users and the number of types of work carried out.

The same thing happens in the use of electrical energy on campuses as institutions providing educational services. The campus is one of the higher education institutions that use large amounts of electrical energy [2]. A study shows that a campus building in the United States with a size of about 50,000 ft2 consumes energy at a cost of more than 100,000 USD every year. Most of the energy is used for lighting and air conditioning equipment [3]. Since 2008, the Malaysian government has implemented a rule that every campus building that consumes electrical energy equal to or more than 3,000,000 kWh for a period of six consecutive months is required to comply with energy-saving requirements and conduct an energy use audit [4]. Peerapong and Limmeechokchai [5] analyzed the feasibility of upgrading solar photovoltaic (PV) power sources in existing diesel-based systems. They found that hybrid PV/diesel systems not only reduce electricity generation costs but also lower harmful emissions from fossil fuels. Maleki and Rosen [6] investigated the performance of a hybrid energy system consisting of fuel cells and wind turbines for residential buildings in Iran. They demonstrated that the use of heat from waste fuel cells may improve system operation and increase its economic justification and reliability.

Therefore, innovative efforts and breakthroughs are needed to overcome the high cost of using electrical energy on campus [7]. One of the solutions is to design and implement a hybrid energy power plant. Hybrid power plants combine the use of energy supplied from the grid system network of the state electricity company (Indonesian: "*Perusahaan Listrik Negara*" (PLN)) and electricity from solar energy sources, namely PV power plants.

The new campus of the State University of Gorontalo (UNG) in Bone Bolango Regency has 4 faculties and 1 library. This campus uses electrical energy from the grid of PLN with an average power of 95,461 kWh with an average cost per month of 83,067,250 IDR (source: general affairs and finance division of State University of Gorontalo, 2022).

By considering the burden of payment for electrical energy which is quite large, it is deemed necessary to make efforts to save the use of electrical energy through the use of renewable energy sources [8]. The potential renewable energy source available at the new campus of the UNG, Bone Bolango Regency, is solar energy. Solar energy is a renewable energy source that is available and free to use. However, the utilization of solar energy with a non-grid system must use a large number of solar cell units so that the costs required are quite large [9]. To produce large amounts of energy, we need large solar cell units and inverter units which have a very high cost [10]. For this reason, it is necessary to combine the use of energy sources from grid connection with PVs in the form of a hybrid energy power plant. A power plant with a hybrid system is a generator that combines 2 (two) or more sources of electrical energy [11]. The hybrid power plant combines the grid-connected electricity source and the electricity from the PV power plant. The hybrid system is an alternative to save electricity usage [12].

To obtain a good value for saving electrical energy, the hybrid power plant must be designed properly and reliably, thereby making it possible to be used continuously for a long time. The obstacle that is often experienced in the use of PV is the rapid breakdown of the PV component system (solar cell) [13]. It is due to the lack of good design, loading system for PV power plants, and the maintenance process. Many PV power generation systems are installed to carry a full load of electrical power. In addition, the electricity storage battery is used until the battery power runs out [14]. The use of PV on a large scale (to supply electricity to campus buildings) requires careful planning and efforts to save the use of electrical energy. This study aims to design a hybrid power plant with a synchronization controller system. It is a system used to control electrical loading according to the electrical power output capability of the PV system. When the PV ability decreases to supply power to the load, the synchronization controller system will automatically transfer the electrical power load to the connected grid. Conversely, the greater the PV power capability is, the power supply to the load previously borne by the connected grid will automatically be transferred to the PV system.

This study also analyzed the investment costs needed for the construction of a hybrid power plant with the synchronization controller and the economic savings that can be obtained after implementing a hybrid power plant at the campus of the State University of Gorontalo. The economic analysis also determined the return on investment (ROI) for the construction of a hybrid power plant so that the operation of the hybrid power plant with a synchronization controller system can be carried out properly and effectively.

2. MATERIALS AND METHODS

In this study, the researchers employed the life cycle cost analysis (LCCA) model for designing and analyzing the economic aspect. The researchers designed a hybrid power plant with the synchronization controller system as a solution for saving the use of electrical energy at the UNG. The hybrid power plant was designed to use 2 energy sources, namely, energy sourced from the PLN and energy from rooftop PV power plants.

2.1. Research materials and data

The materials used in this study were as:

– GPS with the type Garmin GPS 72 H to determine the coordinates of the research location.
– ArcGIS 10.7 – software to process the map of the research location.
– The topographic map of Bone Bolango Regency, Gorontalo.
– Solar cell with a power of 300 WP, the specification of polycrystalline silicon, dimensions of 1,955 mm × 992 mm × 40 mm, a maximum power current of 8.28 A, a maximum voltage of 36.2 volts, an open circuit VOC of 43.4 volts, and a module efficiency of 16.01%.
– A synchronization controller module circuit with a type of Arduino Nano V3.0.
– A data storage logger using memory card microSD V-Gen 32 Gb.
– Digital volt and ampere meters.

The data used in this study were as:

– Solar cell power output data (hourly data) in September 2022, which was measured directly at the Faculty of Engineering of the UNG.
– Solar intensity data (hourly data) from January to September 2022, which were external data from the Climatology, Meteorology, and Geophysics Agency of Bone Bolango, Gorontalo.
– Data on the roof area of the campus building of the UNG, which was obtained through geography information system (GIS) analysis using satellite photos for the area of Bone Bolango for 2022.

Solar intensity data were used as an independent variable to determine the characteristics and performance of PV in generating electric current. With the linear regression analysis method (using Microsoft Excel), the researchers carried out data comparisons referring to the same time of occurrence to obtain the equation of the linear regression line. The obtained linear regression line equation was used to predict solar cell power data (abscissa-Y) in January-September 2022 as data influenced by solar intensity data (abscissa-X) in January-September 2022. The roof area data were used for plotting the number of rooftop solar cells installed on the roof area of the building adjusted to the solar cell dimensions.

2.2. Photovoltaic performance measurement

PV potential in generating electrical energy based on the length of time of solar radiation was measured directly by installing 1 solar cell module with a power of 300 WP and the specification of polycrystalline silicon. The polycrystalline silicon solar cell type was chosen because this type has a fairly good performance even in cloudy conditions [15]. PVs were installed according to the coordinates of the research location (i.e., the Faculty of Engineering, UNG). In recording PV performance, the researchers used an electronic logger installed together with the synchronization controller electronic module. To analyze the number of solar cells to be installed on the roof of the building, the roof area of the building was first measured using the GIS analysis method. The number of rooftop solar cells to be installed was obtained based on plotting according to the dimensions of the solar cell on the available roof area.

2.3. Research flow

The research flow was as shown in Figure 1.

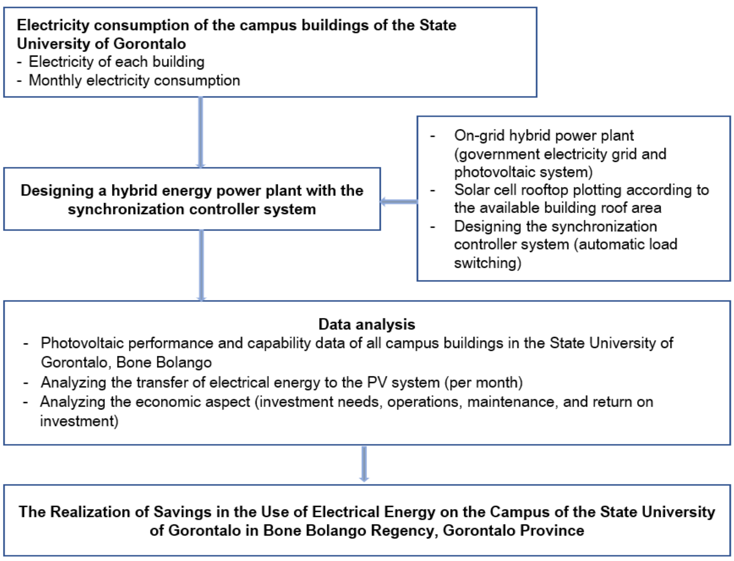


Figure 1. The research flow

3. THEORY/CALCULATION

3.1. Solar radiation and photovoltaic energy

Solar radiation is solar energy that reaches the earth's surface. Radiation consists of three components, namely direct beam, diffuse, and ground-reflected radiations [16]. The direct beam is the direct emission of solar energy and is intercepted by a surface without interaction with many particles in the atmosphere [17]. Diffuse is radiation scattered and intercepted in the atmosphere by aerosols and gases [18]. Meanwhile, ground-reflected radiation is the reflection of radiation from the plane and surrounding surfaces.

Solar radiation can be utilized and converted into electrical energy with PV technology. PV cells generate electrical energy by absorbing photons and releasing electrons which can be captured in the form of an electric current [19]. The cells can be grouped into modules and arrays to generate larger amounts of power to be used individually to power electrical equipment. The potential of rooftop PV power generation depends on several conditions, such as temporal, global, local, and spatial variables [20]. The factor that affects the generation of electricity is the total solar radiation that penetrates the earth's surface. Solar radiation that illuminates the solar cell with an area according to the roof area of the building is a component in estimating the potential of a PV system. The solar radiation data used in this study were sourced from the Meteorology, Climatology, and Geophysics Agency of Bone Bolango Regency in 2022, in which the station measuring solar radiation is located close to the research site.

3.2. Photovoltaic rooftop

The number of solar cells installed was adjusted to the capacity of the roof area of the building with a certain percentage [21]. The study to estimate the rooftop PV potential was carried out by calculating the roof area of the building using the GIS analysis method [22]. The dimension of solar cells with a power of 300 WP and the specification of polycrystalline silicon is of 1,955 mm × 992 mm × 40 mm. Its rectangular area is length×width=2×1 m=2 m^2. The availability of building roof space to capture solar energy can be referred to as the available roof area for PV installations [23]. The potential of the rooftop PV system can be estimated by calculating the potential capacity of the CR rooftop PV system in kilowatt-peak (kWp) using (1) [24]:

$$C_R = \left(\frac{C_M}{1000}\right) \times \left(\frac{RCR \ x \ A_R}{A_M}\right) \quad (1)$$

where: AR is the amount of roof area available for installation of the solar modules in m^2; CM is the individual module rated with capacity in Wp; AM is the area of one module in m^2; RCR is the roof cover ratio, which is the part of roof area that the modules will cover.

Energy yield (E) in kilowatt-hour (kWh) is calculated using (2):

$$E = CR \times GSR \times D \quad (2)$$

where: GSR is the average global solar radiation over 5 years period in kWh/m^2/month. D is the derate factor value, that is converting direct current (DC) to alternating current (AC). The rate factor value ranges between 0.6 and 0.8. Some important things that must be analyzed before installing rooftop PVs are:

- Certain roof orientations that allow shadow effects to appear,
- Analysis of the strength of the roof/wall structure/solar panel installation area, and
- Shading analysis to determine the sunlight that falls on the solar module so that it is not blocked by objects around it.

The analysis process for the rooftop PV installation is shown in Figure 2 (see in Appendix).

4. RESULTS AND DISCUSSION

4.1. Conditions of research location

The campus of the UNG in Bone Bolango Regency, Gorontalo as the research location in this study is located at coordinates 0°33'21.51"N and 123° 7'59.65"E. This campus has 4 faculty buildings and 1 library building. Calculation of the building roof area for rooftop PV installation takes the example of the building of the Faculty of Engineering, as shown in Figure 3. Based on the results of the measurement using the GIS spatial measurement method, the roof area of each section in the building of the Faculty of Engineering is shown in Table 1.

Free area is an area provided for the installation and maintenance of solar cells, such as the passageway between the roofs and the entrance to the roof of the building. The free area is set at 15% of the roof area of each section. Based on the same measurement method, the obtained area for the installation of solar cells in another building on the UNG campus in Bone Bolango was: i) Faculty of Mathematics and Natural

Sciences=2,885.26 m^2, ii) Faculty of Agriculture=1,951.00 m^2, iii) Faculty of Literature and Culture=1,742.81 m^2, and iv) library=470.06 m^2.

Figure 3. The roof area of the Faculty of Engineering measured with GIS

Table 1. The roof area of the building of the Faculty of Engineering for installed solar cells (source: results of GIS analysis, 2022)

No.	Name of building section	Building roof area (m^2)	Free area (15%)	Area for solar cell (m^2)
1.	C2	1,276.77	191.52	1,085.25
2.	C3	636.49	95.47	541.02
3.	C4	460.83	69.12	391.71
4.	C5	541.23	81.18	460.05
5.	C6	396.73	59.51	337.22
6.	Civil laboratory	926.80	139.02	787.78
7.	Industrial laboratory	620.10	93.02	527.09
		Total		4,130.11

4.2. Electrical energy usage

The use of electrical energy in the UNG campus in Bone Bolango in 2022 is as follows. The use of electrical energy in January was 98,940 kWh with a cost of 87,240,826 IDR. In February, it was 98,220 kWh with a cost of 86,413,960 IDR. In March, it was 88,740 kWh with a cost of 77,163,975 IDR. In April, it was 108,210 kWh with a cost of 92,863,575 IDR. In May, it was 83,460 kWh with a cost of 72,588,600 IDR. In June, it was 97,120 kWh with a cost of 83,492,325 IDR. In July, it was 98,940 kWh with a cost of 87,240,825 IDR. In August, it was 81,600 with a cost of 71,089,200 IDR. Lastly, in September, it was 103,920 with a cost of 89,511,975 IDR.

Thus, the total use of electrical energy at the UNG campus in Bone Bolango from January to September 2022 was 859,150 kWh with a cost of 747,605,261 IDR. Based on the results of the energy consumption intensity analysis, electrical energy at the UNG campus in Bone Bolango was consumed more by air condition (AC) electrical equipment, followed by computers and internet, laboratories, lighting needs, and other electrical equipment needs (refrigerators, sound systems, and dispensers). Electrical energy consumption at the UNG campus in Bone Bolango from January to September 2022 is shown in Figure 4. Based on the results of the analysis of the energy consumption intensity in which the largest energy consumption is used for AC, the management of the UNG is expected to make a policy of saving energy use by implementing procedures for the use of energy-efficient AC.

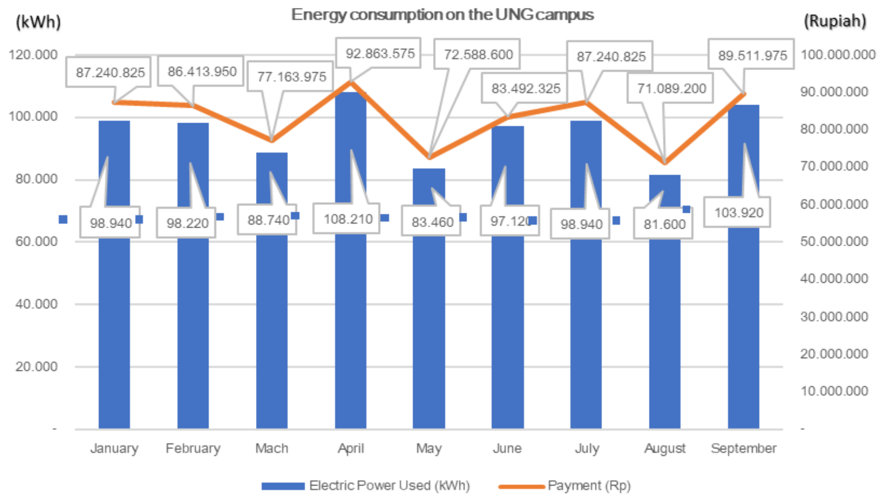


Figure 4. Consumption of electrical energy at the UNG campus in Bone Bolango from January to September 2022

4.3. Photovoltaic performance

Installation of the rooftop solar cell module is conducted by plotting according to the dimensions of the solar cell on the available roof area. For the case of installation on the roof of the UNG campus in Bone Bolango, the researchers carried out the process as shown in Figure 5. The total roof area of the Faculty of Engineering is 4,130.11 m^2. Based on the plotting process adjusted to the dimensions of the solar cell, the roof area that can be used for solar cell installation is 3,064 m^2 or 74.19%. The results of the plotting indicated that the number of solar cells with dimensions of 1,955 mm × 992 mm × 40 mm, which could be installed on the roof of the building, was 383 modules. In addition, those in the building of the Faculty of Mathematics and Natural Sciences Building were 199 modules. Those in the building of the Faculty of Agriculture were 135 modules. Furthermore, those in the building of the Faculty of Literature and Culture were 120 modules. Lastly, those in the library were 32 modules. Thus, the total number of solar cells that could be installed on the roof of the UNG campus in Bone Bolango was 869 modules.

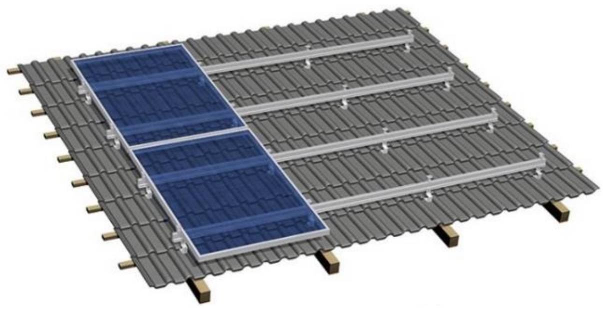
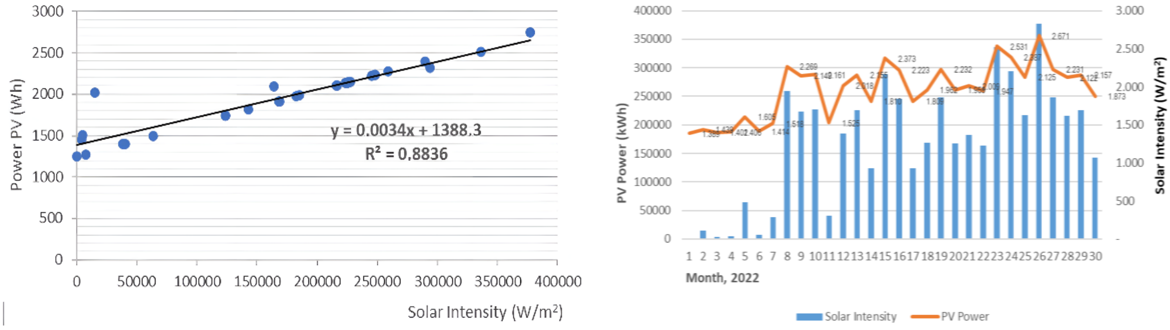


Figure 5. The process of plotting the rooftop solar cell installation area

PV performance is the ability of PV to generate electrical power during solar radiation. The testing process was carried out by installing 1 solar cell module using a pole that is estimated to be in line with the height of the building. The solar cell was installed obliquely 10° to the east. Measurement of solar cell power was carried out on September 1–30, 2022 from 06.00 to 18.00 (for 12 hours). The result of the measurement of the total PV power was 78,874 Wh.

To predict the value of PV power from January to September 2022, the researchers applied a linear regression analysis method with the solar intensity data as the independent variable (in the abscissa-X) and the PV power value as the dependent or affected variable (in the abscissa-Y). The results of linear regression analysis using Microsoft Excel showed a regression equation of Y=0.0034 X+1388.30, as shown in Figure 6(a). In addition, the results of the PV power analysis for September 2022 are shown in Figure 6(b).



(a) (b)

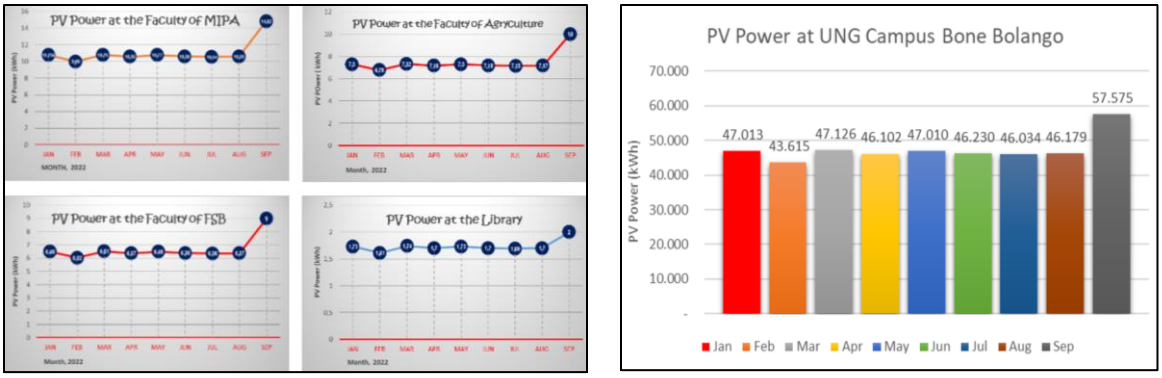
Figure 6. Results of linear regression equation analysis: (a) equation of linear regression line of solar intensity vs PV power in September 2022 and (b) graph of PV power based on solar intensity in September 2022

The electrical power that can be produced by the PV system at the Faculty of Engineering, UNG from January to September 2022 during sunlight hours (i.e., 06.00–18.00) was obtained using (3):

$$ETot = EPV.effPV.nPV \; Watt - hour \; (Wh) \tag{3}$$

where: EPV is the PV output power during sunlight (Wh); $effPV$ is PV efficiency; nPV is the number of solar cells that can be installed on the roof area of the building. Based on (3) in which the PV output power is 78,874 Wh per 1 module, PV efficiency is 16.2%, and the number of solar cells that can be installed on the roof area is 383 modules, the total PV output power obtained at the Faculty of Engineering in September 2022 is 25,375 kWh. The PV power graph from January to September 2022 based on the monthly solar intensity at the Faculty of Engineering is shown in Figures 7(a) to 7(h) (see in Appendix). The electricity generated by PV in January was 20,720 kWh. In February, it was 19,222 kWh. In March, it was 20,770 kWh. In April, it was 20,319 kWh. In May, it was 20,719 kWh. In June, it was 20,375 kWh. In July, it was 20,289 kWh. In August, it was 20,353 kWh. At last, in September, it was 25,375 kWh. Thus, the total electrical power produced by PV at the Faculty of Engineering from January to September 2022 was 188,142 kWh.

In the same way in calculating the PV power of buildings, we can obtain the value of the PV power of other buildings from January to September 2022, as shown in Figure 8(a). Moreover, Figure 8(b) showed the total electrical energy produced by PV from January to September 2022. Based on data presented in Figure 8, the total electric power that can be generated by the PV system from January to September 2022 at the UNG campus in Bone Bolango was 426,884 kWh.



(a) (b)

Figure 8. PV power generated at the UNG campus in Bone Bolango: (a) PV power in every UNG campus building in Bone Bolango from January to September 2021 and (b) PV power in the UNG campus building in Bone Bolango from January to September 2021.

4.4. Synchronization controller system

The synchronization controller is a control system for switching the load supply to PVs when the PV capacity meets the load-carrying capacity. When the PV capacity drops, the load is transferred back to the grid system. The load transfer settings in the synchronization controller system are divided into stages. It is taken so that when there is a decrease in PV capacity, the load can be gradually shifted back to the grid system. The contactor C1-PV will turn off, while the contactor C1-G will on automatically and switch the supply of electrical power to the grid system. If the PV capability continues to decrease, the contactor C2-PV will turn off and automatically turn on the contactor C2-G and switch the power supply to the grid system. If the PV capability continues to decline again, the contactor C3-PV will turn off and automatically turn on the contactor C3-G and switch the electrical power supply to the entire grid system. Likewise, when PV can carry a load, it automatically turns on the contactor C3-PV and turns off the contractor C3-G. Furthermore, when the PV capability continues to rise, then C2-PV will turn on and off C2-G. Additionally, if the condition continues, C1-PV turns on and off C1-G so that the load is supplied again from the PV system. The load transfer system of the synchronization controller is illustrated in Figure 9, which consists of two main components. Figure 9(a) shows the synchronization controller system, and Figure 9(b) depicts the load switching driver using the Arduino Nano V3.0.

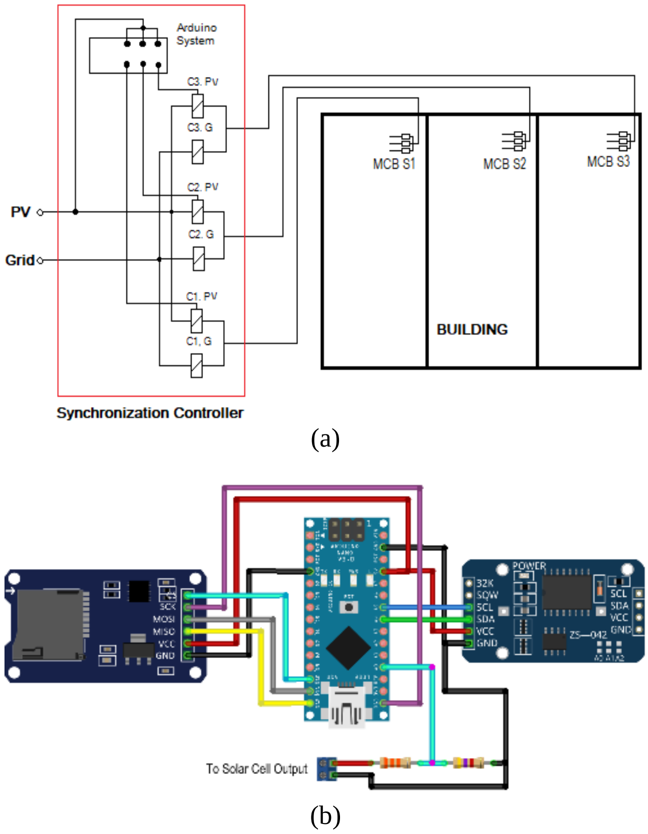


Figure 9. The automatic load switching system from the grid to PV: (a) the synchronization controller system and (b) load switching driver using Arduino Nano V3.0 system

4.5. Economic analysis

4.5.1. Analysis of the value of investment, operation, and maintenance needs

The results of the analysis of investment, operation, and maintenance needs for the construction of an on-grid hybrid power plant at the Faculty of Engineering of the UNG are shown in Table 2.

By employing the same analysis, the cost requirements for other buildings are:

– The cost of hybrid PV development for the Faculty of Literature and Culture=2,247,720,000 IDR
– The cost of hybrid PV development for the Faculty of Agriculture=1,720,675,000 IDR
– The cost of hybrid PV development for the Faculty of Mathematics and Natural Sciences=2,530,550,000 IDR

– The cost of hybrid PV development for the library building=410,000,000 IDR
– Total cost=6,908,945,000 IDR

The total cost of hybrid PV development at the UNG campus in Bone Bolango=10,747,886,800 IDR.

Table 2. Investment, operation, and maintenance needs

No	Tools and materials	Volume	Type of item	Price per item (IDR)	Total (IDR)
1.	Solar panel 300 WP	383	module	5,100,000	1,953,300,000
2.	TH-12 Growatt 15000 W 13000 W 12 kW on grid inverter with multi MPP controller 13 kW grid tie inverter	10	unit	14,272,505	142,725,050
3.	Contact panel	1	unit	22,800,000	22,800,000
4.	Synchronization controller	1	unit	50,000,000	50,000,000
5.	Iron square 50×50×4 mm	932	item	150,000	139,800,000
6.	Hollow iron 40×60×2 mm	655	item	210,000	137,550,000
7.	Bolts and nuts M8×15 mm	6,000	item	372	2,232,000
8.	Bolts and nuts M8×60 mm	2,500	item	686	1,715,000
9.	Connector MC4	700	item	45	31,500
10.	Connector MC4 Y	150	item	155	23,250
11.	Cable	500	roll	180	90,000
12.	Aluminum rail 2.1 m	632	item	1,500,000	948,000,000
13.	Rail connection	346	item	125,000	43,250,000
14.	Edge clamp	408	item	50,000	20,400,000
15.	Middle clamp	720	item	50,000	36,000,000
16.	Rail hook	1,867	item	75,000	140,025,000
17.	Shipping costs	1	package	25,000,000	25,000,000
18.	Workmanship cost	1	package	75,000,000	75,000,000
18.	Setting fee	1	package	25,000,000	25,000,000
	Total				3,762,941,800
20.	Operational costs	1	per 1 month		26,000,000
21.	Maintenance costs	1	per 1 month		50,000,000
	Total				3,838,941,800

4.5.2. Analysis of the value of saving the use of electrical energy

Savings in electric energy cost are analyzed using (4).

$$Value\ of\ savings\ =\ Cost\ for\ energy\ use\ -\ Cost\ of\ energy\ supplied\ from\ the\ PV\ system \tag{4}$$

The electrical energy used at the UNG campus in Bone Bolango in September 2022 was 103,920 kWh with a cost of 89,511,975 IDR. Meanwhile, the electrical energy generated by the PV system in September 2022 was 57,575 kWh. Based on Indonesia's Minister of Energy and Mineral Resources Regulation No. 730/2021, the purchase of electricity from rooftop PV power plants is set at 1,440 IDR per kWh. Thus, the value of the purchase of PV system energy can be calculated, namely 57,575 kWh × 1,440 IDR=82,908,000 IDR. The values of saving the use of electrical energy and saving on electricity costs at the UNG campus are shown in Table 3. The results of the analysis showed that the application of a hybrid power plant with a synchronization controller system at the UNG campus in Bone Bolango from January to September 2022 can generate electrical energy savings of 426,975 kWh with a cost of 614,844,000 IDR or 82% of the burden of the cost of using electrical energy.

Table 3. Savings in the use of electrical energy at the UNG campus in Bone Bolango

No	Months	Electrical energy usage		Electrical energy from the PV system		Savings percentage	
		Electrical power (kWh)	Cost (IDR)	Electrical power (kWh)	Cost (IDR)	Electrical power (%)	Cost (%)
1.	January	98,940	87,240,825	47,013	67,698,720	52	78
2.	February	98,220	86,413,950	43,615	62,805,600	56	73
3.	March	88,740	77,163,975	47,126	67,861,440	47	88
4.	April	108,210	92,863,575	46,102	66,386,880	57	71
5.	May	83,460	72,588,600	47,101	67,825,440	44	93
6.	June	97,120	83,492,325	46,230	66,571,200	52	80
7.	July	98,940	87,240,825	46,034	66,288,960	53	76
8.	August	81,600	71,089,200	46,179	66,497,760	43	94
9.	September	103,920	89,511,975	57,575	82,908,000	45	93
	Total	859,150	747,605,250	426,975	614,844,000	50	82

4.5.3. Analysis of return on investment

The ROI calculation analysis was carried out referring to Indonesia's Minister of Energy and Mineral Resources Regulation No. 730/HK.01/SJN.H/2021 dated June 22, 2021, regarding the purchase of rooftop PV electricity by the PLN. The regulation mentions that the purchase of electricity from rooftop PV power plants is set at 1,440 IDR per kWh. The total power generated by PV from January to September 2022 was 426,975 kWh. In other words, the income generated can be calculated as: 1,440 IDR × 426,975 kWh= 614,844,000 IDR.

– Payback period

The total investment required for the construction, operation, and maintenance of the hybrid power plant is 10,747,886,800 IDR. Thus, by using the payback period method, the ROI can be calculated as:

$$Payback\ Period\ =\ Total\ Investment\ /\ Net\ Cash\ Flow$$

The net cash flow for January to September was 614,844,000 IDR. With the average value of electrical energy produced by PV from January to September (i.e., 47,432 kWh), it can be estimated that the electrical energy produced by PV from October to December will be 142,295 kWh with a cost-income of 204,904,320 IDR. Therefore, the total cost income for 1 year (January-December) will be 819,748,320 IDR.

$$Payback\ Period\ =\ 10{,}747{,}886{,}800\ /\ 819{,}748{,}320\ =\ 13\ Years$$

5. CONCLUSION

The use of PVs in an on-grid hybrid energy power generation system is a solution to saving the use of electrical energy. The results of this study showed that the hybrid energy power plant with a synchronization controller system which was applied at the campus of the UNG in Bone Bolango Regency by combining the government electricity grid system and PV energy electricity was highly effective in saving the cost for the use of electrical energy, namely 68,301,440 IDR or 82% of the monthly electricity bill. The investment required for the construction, operation, and maintenance of this hybrid power plant is 10,747,886,800 IDR. Furthermore, ROI can be obtained for 13 years.

ACKNOWLEDGEMENTS

Thanks to the Lembaga Penelitian dan Pengabdian Masyarakat Universitas Negeri Gorontalo, which has provided research funding grants, on letter number: B/172/UN47.D1/PT.01.03/2022.

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APPENDIX

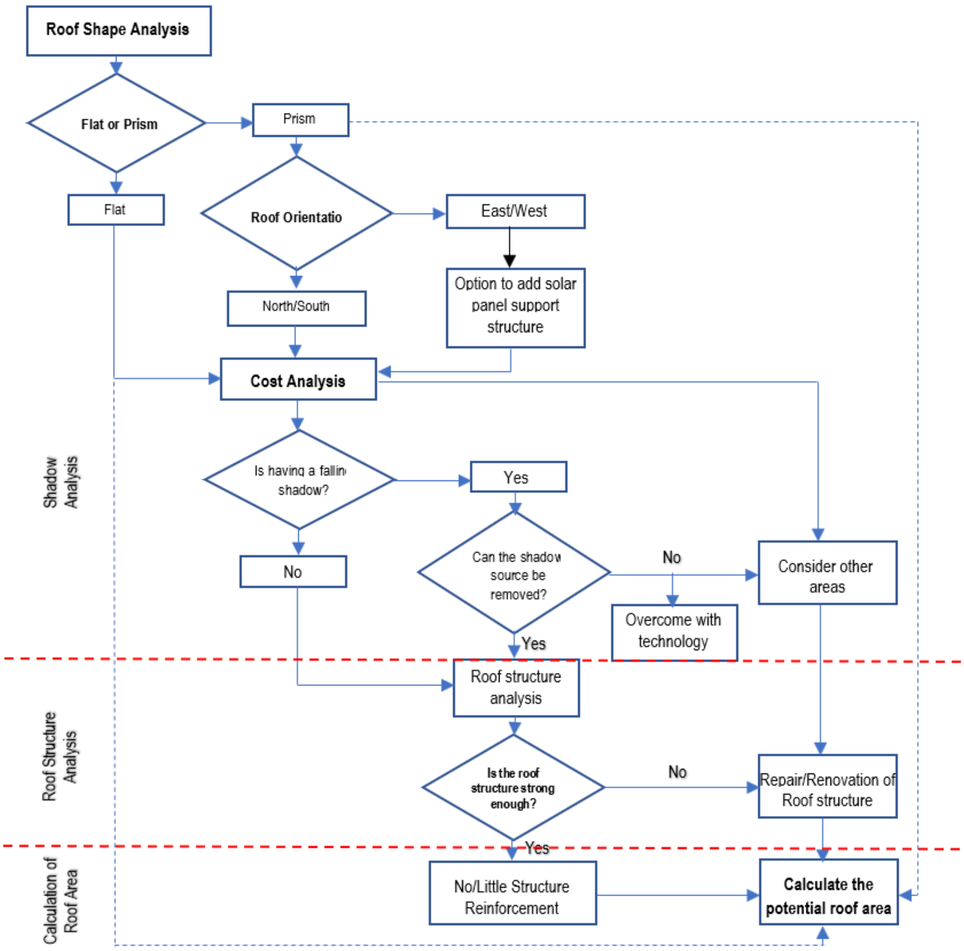

Figure 2. The flow in installing rooftop photovoltaics

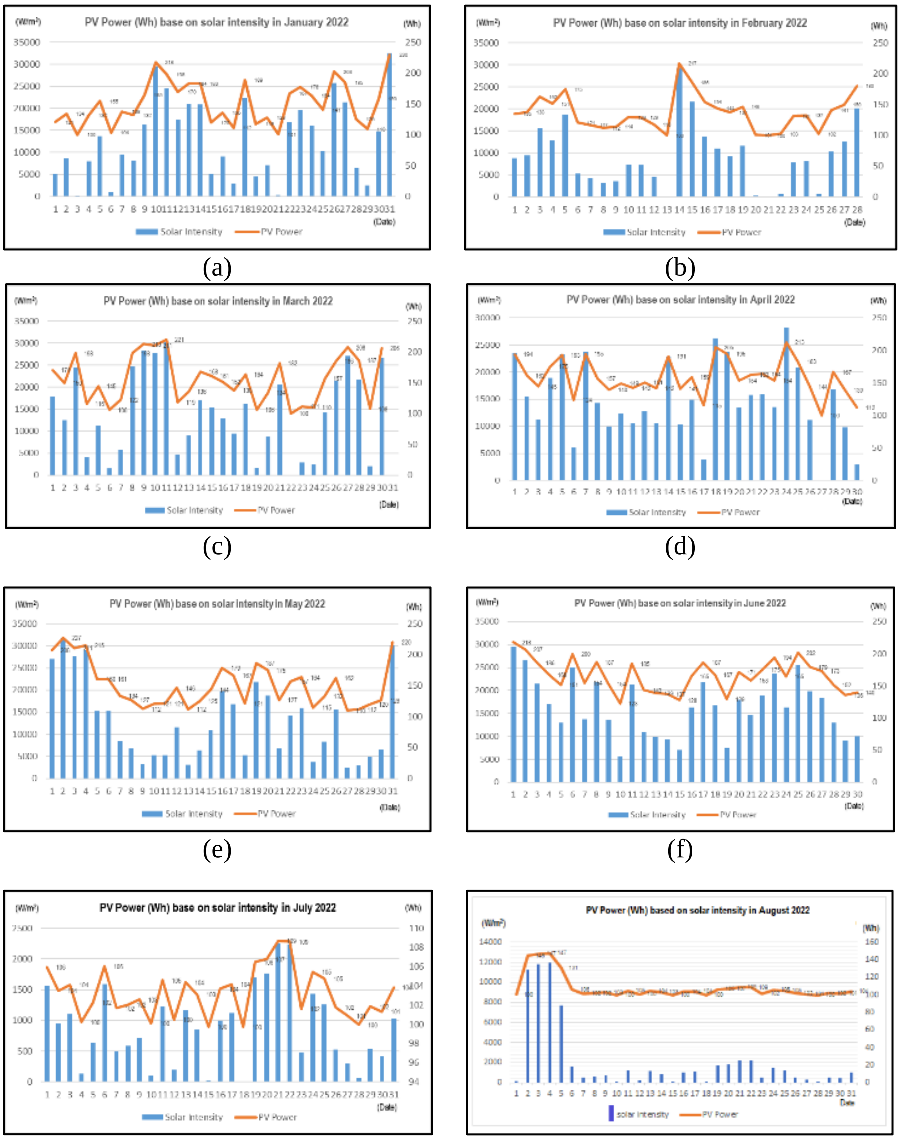

Figure 7. Power graph of the PV system generated at the building of the Faculty of Engineering of the State University of Gorontalo: (a) PV power in January 2022, (b) PV power in February 2022, (c) PV power in March 2022, (d) PV power in April 2022, (e) PV power in May 2022, (f) PV power in June 2022, (g) PV power in July 2022, and (h) PV power in Augustus 2022